Chapter 2
Sewer Sediment

Sources of Sewer Sediment

The sediment-solids and associated pollutants found in combined sewer overflow result from resuspension of deposited DWF sanitary wastewater solids and wash-off from land surfaces during storm events. A review of the sources (Heaney et al., 1999) shows that directly-connected impervious areas contribute a high pollutant loading in separate storm sewers. For combined sewers, the largest solids and pollutant loads are likely to originate from sanitary wastewater input during dry weather. Ashley and Hvitved-Jacobsen (2002) categorized sources of sediment solids as shown in Table 1.

Table 1. Sources of sewer sediment

Source	Particle Characteristics	Description
Winter gritting/salting	Salt <1.5 mm, sand 1.3 mm.	Sand used up to 30% of total mass annually.
Road surfacing	All sizes possible.	Primarily inorganic.
Flow from ground	All sizes possible	Depending on sewer condition.
Industrial wastewater	Pretreatment standards	Pretreatment removal of toxic solids.
Construction sites	>1000 mm possible	All sizes organic, inorganic possible.
Flooding	>1000 mm possible	All sizes organic, inorganic possible.
Runoff from impervious areas	Typically solids < 250 μm enter sewer.	These solids may be up to 40% by mass of total. Roof surface up to 30% of total.
Sanitary wastewater	Up to 100 mm	Largest organic solids source – typically 97% of these solids. All enter sewer.
Soil erosion	Typically <1 mm	Organic and inorganic.
Wind-blown from sand/soil/litter	Large organics possible. Inorganics <5 mm	Entry via catchbasins/inlet. Size reduced when discharged into sewer.

Overland Surface Runoff Solids

The particulate and associated pollutants in urban stormwater come from atmospheric deposition, roof tops, parking lots, and streets/highways. Other sources include construction sites, commercial and industrial parking lots, automobile maintenance operations, leaking sewer infrastructure, accidental spills, and runoff from lawn irrigation.

Atmospheric Deposition

In the United States, each year millions of tons of pollutants are emitted into the troposphere zone of the atmosphere; this has the potential to redeposit in the urban and terrestrial watershed and be subsequently transported downstream to receiving waters. The factors affecting atmospheric deposition include wind speed and direction, dry dust fall, site temperature and precipitation (snow and rainfall), elevation and slope of the land, land use, and sources of air pollution (automobile, industrial, and residential emission). Pollutants in the atmosphere contribute significantly in urban WWF contamination through dustfall and by wash out. As reported by Cotham and Bidleman (1995) and Hilts (1996), enormous amounts of certain toxic pollutants contained in urban storm runoff are associated with atmospheric deposition.

Rooftops, Roadways, and Parking Lots

One of the major sources of pollutants in urban drainage catchments are runoff from: urban streets (Sansalon, 1996; Sansalone and Buchberger, 1996), highways (Shaheen, 1975; Montrejaud-Vignoles et al., 1996), building rooftops (Sakakibara, 1996; Förster, 1996; and Wada et al., 1996), and parking areas (Pitt et al., 1995; Nowakowska-Blaszezyk and Zakrzewski, 1996). In some cases, treated wood has been identified as a potential source of arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), and zinc (Zn) in stormwater (Weis and Weis, 1996). Table 2 depicts relationships between toxic pollutants in solids and urban land use.

Table 2. Toxic-pollutant concentrations from land use in France (Bertrand- Krajewski, 1993)

Land Use	Toxic Pollutant Concentration					
	Cd (Fg/g)	Cu (Fg/g)	Pb* (Fg/g)	Zn (Fg/g)	TPHs (mg/g)	PAHs (Fg/g)
Residential area	0.04–10.7	14–221	120–1,000	47–1,170	15.7–59.8	--
Commercial area	0.02–1.06	10.4	160–220	53–1,065	16.4–34.0	--
City downtown	2.6–7.0	143 - 390	1,880–2,550	470–534	8.8–51.8	--
Industrial area	0.7–3.4	228	488–1,410	655–1,445	61.9–507.0	--
Parking lot	1.0–14.6	206	2,000–15,000	1,600	--	--
Street	0.22–3.90	22–200	--	44–480	--	0.2–20
Highway	0.6–4.3	90–281	130–4,800	250–336	--	--

* Pb relates to the use of leaded gasoline.
Legend: Cd-cadmium, Cu-copper, Pb-lead, and Zn-zinc.
TPHs-total petroleum hydrocarbons, and PAHs-polycyclic aromatic hydrocarbons.

Distributions of heavy metals and hydrocarbons in urban stormwater are associated with their particulate fractions and the relative size of SS. Particles finer than 250 :m contain higher concentration of heavy metals and total petroleum hydrocarbons (TPHs) than particles larger than 250 :m and about 70% of the heavy metals are attached to particles finer than 100 :m (Ellis and Revitt, 1982). Vignoles and Herremans (1995) examined the heavy metal associations with different particles sizes in stormwater samples from Toulouse, France and discovered that the vast majority of the heavy metal loadings in stormwater were associated with particles less than 10 Fm in size. These results are shown in Table 3.

Table 3. Concentration of metals by size fraction

Particle Size Range (μm)	Metal Concentration															
	Cd		Co		Cr		Cu		Mn		Ni		Pb		Zn	
	μg/g	%*	μg/g	%*	μg/g	%*	μg/g	%*	μg/g	%*	μg/g	%*	μg/g	%*	μg/g	%*
> 100	13	18	18	9	21	5	42	7	86	8	31	7	104	5	272	7
50 – 100	11	11	16	5	25	4	62	8	59	4	27	5	129	7	419	11
40 – 50	11	6	25	4	26	2	57	3	70	3	31	7	181	10	469	12
32 – 40	6	5	20	6	50	6	46	4	53	3	31	7	163	9	398	10
20 – 32	5	5	18	6	23	3	42	4	54	4	27	5	158	8	331	9
10 – 20	6	9	22	10	39	9	81	11	85	7	39	10	247	14	801	20
< 10	14	46	53	60	134	71	171	63	320	71	99	59	822	46	1232	31

Legend: Cd-cadmium, Co-cobalt, Cr-chromium, Cu-copper, Mn-manganese, Ni-nickel, Pb-lead, and Zn-zinc.
* Distribution of metal pollutant weight among the different particle size range.

Snowmelt runoff is much greater in volume than typically considered in drainage designs, resulting in greater winter flooding than during the summer; however, there is still a notable lack of experience about urban runoff during the winter season (Thorolfsson and Brandt,1996). Saxton *et al.* (1996) conducted a study to characterize the pollution of snow versus snowmelt runoff at Eielson Air Force Base, Alaska and reported that snow was more contaminated than snowmelt runoff and that snowmelt runoff appeared to be representative of what reached surface water. Sansalone (1996) investigated the forms of stormwater and snowmelt heavy metals and reported that Zn, Cd, and Cu were mainly dissolved in stormwater, while only Cd was mainly dissolved in snowmelt.

Sanitary Wastewater Solids

According to Ashley and Hvitved-Jacobsen (2002), solids originating from sanitary wastewater sources can be categorized into the following types:

1. Fine fecal and other organic particles.
2. Large fecal and other organic matter.
3. Paper, rags, and miscellaneous sewage litter.

These categories also apply to commercial and other workplaces, where other substances may be added, subject to effluent controls. Industrial sources are also important, but due to the diversity of the inputs from industrial sources, they will not be considered further here. Garbage grinders, that are installed in many residential areas for disposal of kitchen wastes generate higher organic solids loading. Pollutant loads and concentrations from residential sources discharging to sewers are shown in Table 4.

Table 4. Pollutant loads and concentrations from residential sources (EPA 1992)

Parameter	Garbage Grinders		Toilets		Basins, Sinks, Appliances	
	gpcd	mg/L	gpcd	mg/L	gpcd	mg/L
BOD_5	11 - 31	2380	7 - 24	260	25 - 39	260
SS	16 - 44	3500	13 - 37	450	11 - 23	160
Nitrogen	0.2 - 0.9	79	4.1 - 16.8	140	1.1 - 2.0	17
Phosphorus	0.1	13	0.6 - 1.6	20	2.2 -3 4.	26

Results from the Jefferies and Ashley (1994) study of gross solids discharge in combined sewers can be interpreted to give a rate of 0.05 visible items /capita/day. The average disposal rate reported by Friedler et al. (1996) was 0.15 refuse items/capita/day, 72% of which was due to female toilet usage. The most common item of refuse (23% of those reported) was the tampon. According to Ashley et al. (2000) some 2.5 million tampons, 1.4 million sanitary towels, and 700,000 panty liners were found to be flushed into sewers in the United Kingdom every day. These items become floatable solids in CSO. Thus, the accumulation of trash on beaches and along shorelines of impacted waterways is the most obvious impact of floatable pollution. It is not only in the United Kingdom that the toilet is being used as a rubbish bin. A limited questionnaire survey was undertaken of the items disposed in 72 countries. Results indicated that some 33% of respondents claimed that sanitary items, other than feces and toilet paper, were regularly flushed, and in some countries 'disposable' napkins were also put into the toilet (Ashley et al, 1999). There will not likely be any significant reduction in these items found in sewers in the near future necessitating expensive screens and transport systems for their control and disposal (Ashley et al, 2000).

Impacts

In general, sewers will not maintain self-cleansing velocities at all times. The diurnal pattern of DWF and the temporal distribution and nature of sediments found in sewer flows may result in the deposition of some "juvenile" sediments at times of low flow. The subsequent erosion and transport of these sediments at times of higher flow during a storm-flow event, either as suspended load or bedload, contribute to the "first-flush" phenomena or polluted segment in CSO (Saget et al., 1996; Arthur et al., 1996; Arthur and Ashley, 1998; Krebs et al., 1999). During low flow dry weather periods, sanitary wastewater solids deposited in combined sewer systems can generate H_2S and methane gases due to anaerobic conditions. Sulfates are reduced to H_2S gas that can then be oxidized to sulfuric acid on pipes and structure walls by further biochemical transformation. Furthermore, these sediments are discharged to urban streams during storm-flow events and can cause degradation of receiving water quality. Thus, dry weather sewer sedimentation not only creates hazardous conditions and sewer degradation but also contributes significant pollutant loads to the urban receiving waters during wet-weather high-flow periods. Furthermore, broken sewer lines cause direct exfiltration of raw sanitary wastewater and sewer sediment leachate into subsurface groundwaters.

Structural Deterioration of Sewerage System

The primary cause of odor and corrosion in collection systems is the sulfide ion ($S^=$), which is produced from sulfate ($SO_4^=$) by bacteria residing in a slime layer on the submerged portion of sewer pipes and structures. Once $S^=$ is released from the wastewater as H_2S gas, odor and corrosion problems begin. Bacteria utilize H_2S gas to produce sulfuric acid (H_2SO_4) (Boon, 1995; Boon and Lister, 1975; Thistlethwayte 1972). For sanitary wastewater the main source of $S^=$ is $SO_4^=$. Sulfide generation is a bacterially mediated process occurring in the submerged portion of combined and sanitary sewers and force mains. Fresh sanitary wastewater entering a collection system is usually free of $S^=$. However, a dissolved form of $S^=$ soon appears as a result of low dissolved oxygen content, high-strength wastewater, low flow velocity, long detention time in the collection system, elevated wastewater temperature, and extensive pumping (EPA 1985).

The effect of H_2SO_4 on concrete surfaces in the sewer environment can be devastating. Sections of collection interceptors and entire pump stations have been known to collapse due to loss of structural stability from corrosion. In severe instances, pipe failure, disruption of service, street surface cave-ins, and uncontrolled releases of wastewater to surface streams can occur.

Receiving Water

From 40% to 80% of the total annual organic loading entering receiving waters from a city is caused by WWF. During a single storm event, WWF accounts for about 95% of the organic load as well as high loads of heavy metals and petroleum hydrocarbons (Field and Turkeltaub, 1981). CSO can have damaging impacts on receiving waters. The EPA evaluated the distribution and biological impacts of discharged particulates for selected CSO and storm drain points in the Seattle, Washington region (Tomlinson et al., 1980). The concentrations of SS, heavy metals, and chlorinated hydrocarbons were greater for the CSO than for the storm drains. Particulate distributions were influenced by various dispersion processes, including water density layering, near-bottom offshore streaming and advection along the shoreline Human enteric viruses were also detected in the CSO, but were not found in storm drainage or in any near outfall sediments. However, impacts of discharges on the freshwater benthos raised concern relative to the feeding success of sport fish due to polluted sediments.

Saul et al. (1999) investigated the production of undesirable solids in CSO as it related to social, economic, and ethnic factors. The goals of the research were first to determine the differences in sewer solids characteristics that were ultimately discharged to the receiving water and then to use the solids' characteristics to predict the efficiency of CSO treatment devices, especially CSO storage basins. St. Michelbach and Brombach (1999) showed that the nutrient content, especially of dissolved phosphorus, from CSO and existing WWTPs was endangering the health of Lake Constance. They proposed a simple methodology to estimate the nutrient loads from CSO to the lake the results of which can be used to determine the cost effectiveness of CSO improvement versus WWTP improvement.

Sanudo-Wilhelmy and Gill (1999) compared current pollutant concentrations in the Hudson River Estuary, New York with concentrations measured in the 1970's. The concentrations of Cu, Cd, Ni, and Zn have declined, while concentrations of dissolved nutrients (namely PO_4) have remained relatively constant during the same period. This suggests that WWTP improvements in the New York/New Jersey Metropolitan area have not been as effective at reducing nutrient levels within the estuary as heavy metals. Rather than inputs from point sources, the release of Pb and Hg from watershed soils, and Ni and Cu from estuarine sediments, may represent the primary contemporary sources of these metals to the estuary. Mason et al. (1999) showed that the Chesapeake Bay was an efficient trap for Hg. However, in the estuary, methylation of the mercury occurred, the Bay became a source of methylmercury, and on a watershed scale, only about 5% of the total atmospheric deposition of mercury was exported to the ocean.

Venkatesan et al. (1999) investigated the potential for using sediment cores to determine the history of chlorinated pesticide and PCB application in a watershed. They found that the sediment cores accurately reflected the length of use of these chemicals in the watershed, and that the surface sediment layer, after mixing and resuspension was accounted for, reflected the reduction in use that had occurred during the last few years. The long-term impacts of WWF- toxic pollutants to stream habitat are depended on bio-availability and accumulation of the substances by aquatic life. Herrmann et al. (1999) found that the concentration of ammonia plus urea in CSO was found to be a significant measure of the likelihood of a fish kill after an overflow event, more relevant than the concentration of ammonia alone.

Groundwater

In 1999, the EPA conducted a nationwide study to quantify leakage of sanitary and industrial wastewater sewer systems based on groundwater table elevations. The study indicated low levels of wastewater exfiltration (less than groundwater infiltration) in much of the midwestern and eastern parts of United States due to relatively high groundwater tables. However, problems of exfiltration in the western United States seem more widespread because of lower groundwater table (EPA, 2000). Thus, contamination of soils and groundwater in the vicinity of a leaking sewer does not appear to occur under conditions favorable to the infiltration of groundwater into sanitary sewers. Exfiltration events are likely to be more severe than infiltration events at locations where groundwater fluctuates. Possible groundwater contamination, resulting from sewers that have collapsed or catastrophically failed and from sewers which are believed to suffer from long-term deterioration, has been noted in groundwater contamination studies (EPA, 1989).

In those areas having shallow depth of wells and high permeability of soil, any surface contamination could easily migrate to the groundwater. Thus, a significant amount of groundwater contamination is as attributable to surface runoff as leaky sewer exfiltration. Squillace, et al. (1996) and Zogorski, et al. (1996) investigated urban stormwater as a source of groundwater MTBE contamination. Mull (1996) stated that traffic areas are the third most important source of groundwater contamination in Germany (after abandoned industrial sites and leaky sewers). The most important contaminants are chlorinated hydrocarbons, sulfate, organic compounds, and nitrates. Heavy metals are generally not an important groundwater contaminant because of their affinity for soils.

Trauth and Xanthopoulus (1996) examined the long-term trends in groundwater quality in Karlsruhe, Germany. Results indicated that the urban land use could cause a long-term adverse influence on the groundwater quality. The concentration of many pollutants have increased by about 30% to 40% over 20 yrs. In Dortmund, Germany, an infiltration trench for stormwater disposal caused Zn problems that were associated with the low pH value (about 4) in the infiltration water (Hütter and Remmler,1996).